Emerging Array Antenna Technologies at JPL

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Introduction: JPL/NASA's Earth remote sensing and deep-space exploration programs have been placing emphasis on their spacecraft's high-gain and large-aperture antennas. At the same time, however, low mass and small stowage volume are demanded in order to reduce payload weight and reduce shroud size and thus reduce launch cost. To meet these goals, the concept of an inflatable parabolic reflector was introduced about two decades ago. However, the full implementation of this concept is still hampered by the inability to achieve the required surface accuracy. Even with the technologies of rigidizable membrane, stretchable aluminum, UV-cured polymer, and hardenable gel, it is believed that it will be difficult to maintain the desired parabolic surface accuracy for the duration of long space missions To mitigate the effect of curvature, a new class of planar array technology is being developed. It is believed that it will be significantly easier to maintain the required surface tolerance of a flat structure, such as the planar array, than a curved structure such as a parabola. In addition, a planar array offers the possibility of wide-angle beam scanning which cannot be easily achieved by a parabolic reflector. At JPL, three planar array antenna technologies are being developed. These are microstrip reflectarray[1,2,3], inflatable planar array[4,5], and foldable frame-supported thin-membrane array[4]. They are separately discussed in the following paragraphs.

Microstrip reflectarray: The microstrip reflectarray[1,2] is similar to a parabolic reflector in that it requires a spatial feed element to illuminate a reflecting surface. However, unlike the parabolic reflector, the reflecting surface of the reflectarray is flat. It produces a collimated beam just as a parabolic reflector but, being flat, it can be surface mountable onto an existing flat structure without adding structure supports. Such a flat reflecting surface also lends itself to a simple folding/unfolding mechanism. Two Ka-band half-meter circularly polarized microstrip reflectarrays[3] have recently been developed with excellent results. Both achieved antenna efficiency of more than 50% across a bandwidth of at least 3%. One, shown in Fig. 1, achieved a peak efficiency of 60% with a gain of 42.2 dB as indicated in Fig. 2. The reflectarray surface consists of nearly 7000 square patch elements printed on a 0.25 mm thick dielectric substrate. Such a thin surface can be pasted onto an existing flat structure without adding a significant amount of mass.

Inflatable planar arrays: Two inflatable array antennas that were developed recently are a 3.3 m x 1.0 m L-band synthetic aperture radar (SAR) array[5] for Earth remote sensing application and a 1 m X-band reflectarray[6] for deep-space telecom application. The L-band SAR array, shown in Fig. 3, is a technology demonstration model 1/3 the size of the future full size (10m x 3m) array. It is basically a rectangular frame with inflated tube that supports and tensions the three-layer thin-membrane radiating surface with microstrip patches and microstrip transmission lines. The inflated tube has a diameter of 13 cm and is made of 0.25 mm thick urethane coated Kevlar material. The thin membranes are each made of 5-micron copper on 0.05 mm thick Kapton sheet. The top layer has the radiating microstrip patches and microstrip power dividing lines to generate a horizontally polarized field. The middle ground-plane layer has slots etched through the 5-micron copper layer, with one slot situated below each top-layer patch. The bottom layer has the microstrip lines that excite the top-layer patches to provide a vertically polarized field through the middle-layer slots. The measured results show that the antenna achieved a bandwidth of 80 MHz with a center frequency of 1.25 GHz. The two principal-plane patterns measured at 1.25 GHz are shown in Fig. 4. This uniformly excited array achieved a peak gain of 25.2 dB with an aperture efficiency of 52%. The antenna has a total mass of 15 kg with an average of 4.3 kg/m^2, which includes the inflation system and its support box (total 9 kg). It is projected that the full size (10m x 3m) array would have an average mass of 2 kg/m^2. The membrane surface achieved the required global flatness of less than ± 1 cm and local flatness of ± 0.75 mm.

The inflatable X-band reflectarray antenna[6], shown in Fig. 5, has an inflated torus tube that supports and tensions the one-meter-diameter two-layer-membrane reflectarray surface. The inflated tripod tubes are attached to the torus as struts to support a feed horn. The inflatable tubes and the thin membranes use the same material as that described above for the inflatable SAR array. The top membrane layer is etched to produce many isolated microstrip patches. The bottom layer serves as the ground plane. These two layers are separated 1.3 mm apart. Many small foam discs (7 mm diameter) are placed between the two membranes and are used to maintain a uniform membrane spacing. The inflatable antenna structure achieved a mass of 1.2 kg which excludes the mass of the inflation system. With future development, it is believed that the mass of the inflation system can be on the order of 0.5 kg. A typical measured antenna pattern at 8.3 GHz is given in Fig. 6. The measured peak gain at 8.3 GHz is 33.7 dB which indicates an overall antenna efficiency of 37%, while the expected efficiency should be about 50%. This relatively poor efficiency is primarily due to design and manufacturing inexperience in building this first demonstration model. Imperfect membrane separation, feed and strut blockage, surface roughness, leakage radiation from phase delay lines are all contributors to the inefficiency. All these errors are believed to be correctable for future models to improve their efficiencies.

Foldable frame-supported thin-membrane array: This array concept[4], currently under development at JPL, consists of several foldable panels (8 to 12) that are to be deployed by spring-loaded hinges. Each panel, shown in a sketch in Fig. 7, has a rectangular frame that supports a two-layer, thin-membrane, L-band subarray aperture. The frame is made of very low mass graphite composite material. Two layers of thin membranes, one being the ground plane, are used with microstrip array design to radiate dual-polarized fields with 80 MHz of bandwidth at 1.25 GHz. The chief advantage of this "frame" concept is that each frame is able to rigidly support an appropriate number of T/R modules and phase shifters to achieve the desired RF power distribution and beam scan. With this design, the array can have its main beam scanned ± 20° in the vertical direction and a few degrees in the horizontal direction which is generally required for a modern SAR radar. The estimated average mass for flight versions of this antenna is 3 kg/m^2.

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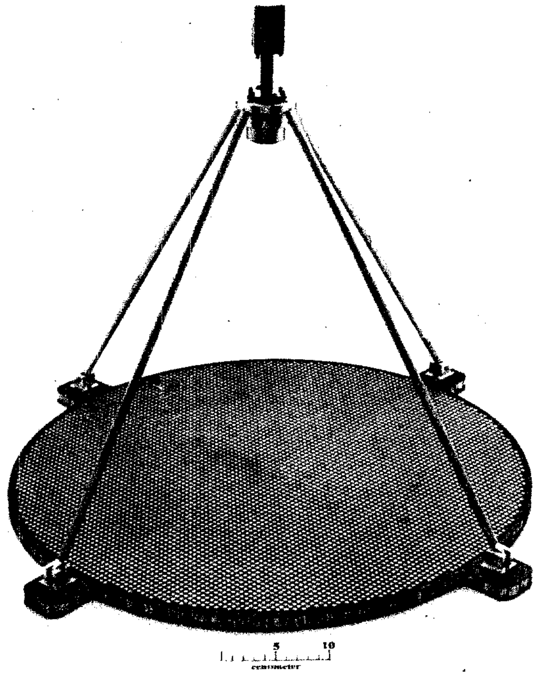

Fig. 1. 32 GHz 0.5-m circularly polarized microstrip reflectarray.

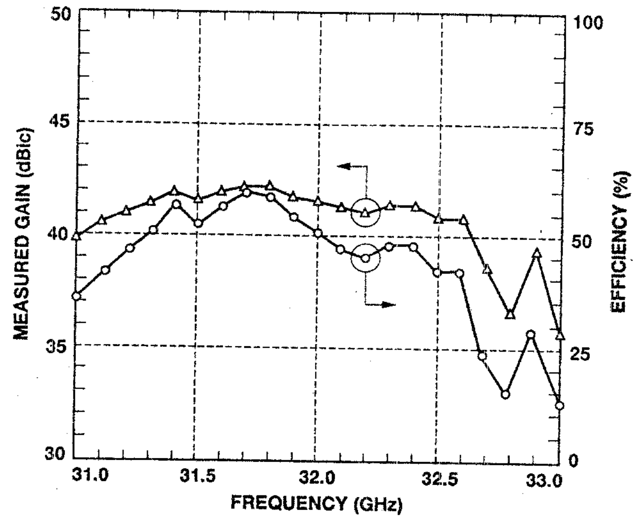

Fig. 2. Efficiency and gain versus frequency of the Ka-band microstrip reflectarray.

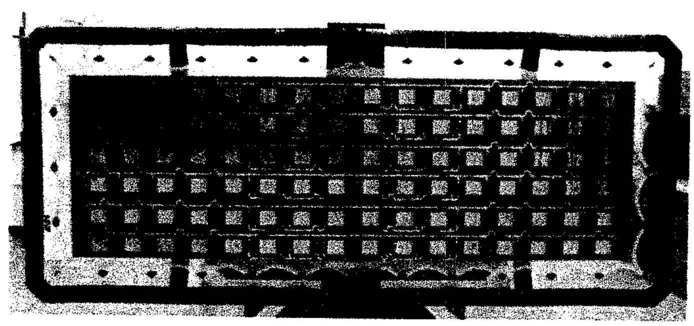

Fig. 3. 3.3m x 1.0m inflatable L-band dual-polarized microstrip SAR array.

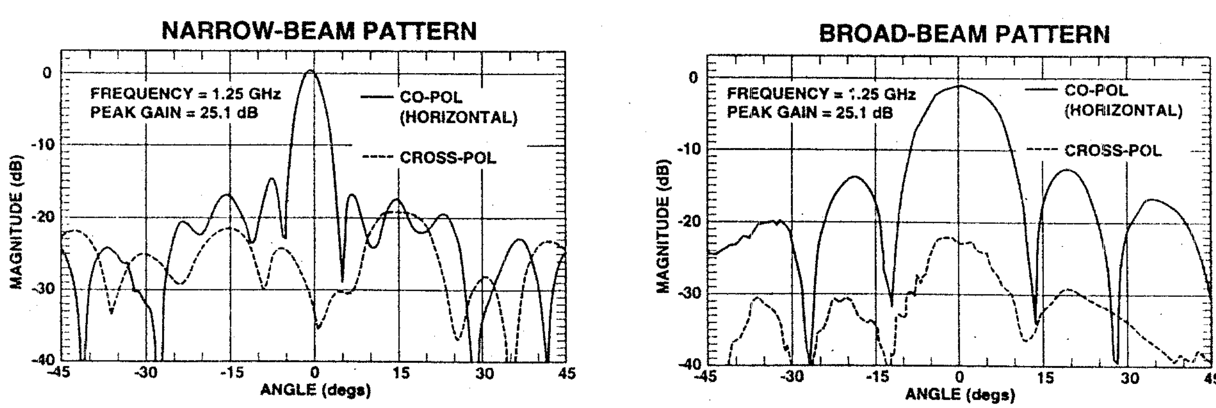

Fig. 4. Measured two principal-plane patterns of the inflatable SAR array.

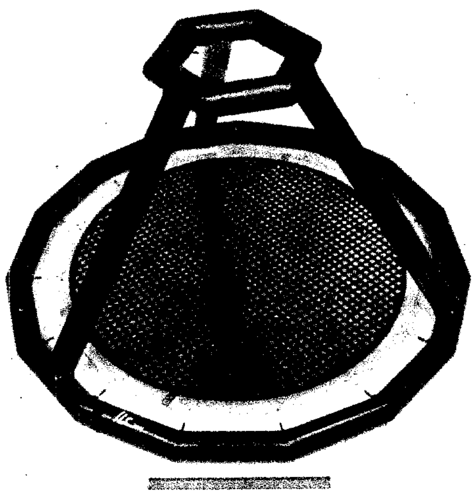

Fig. 5. One-meter X-band inflatable microstrip reflectarray.

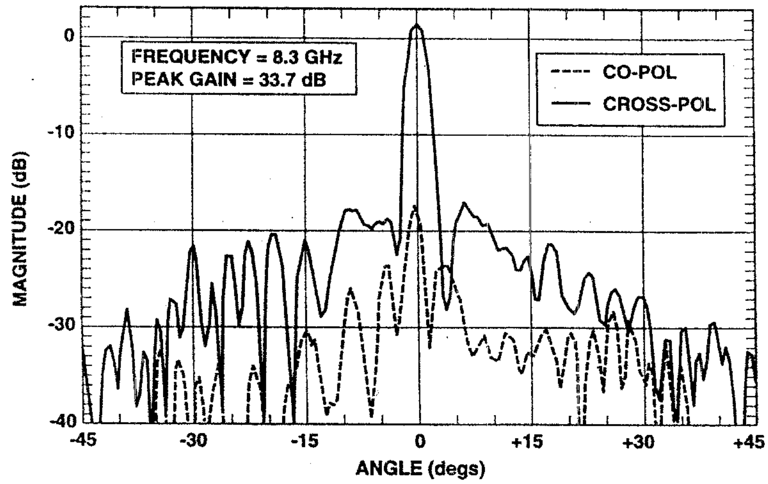

Fig. 6. Measured pattern of the 1-m X-band inflatable reflectarray.

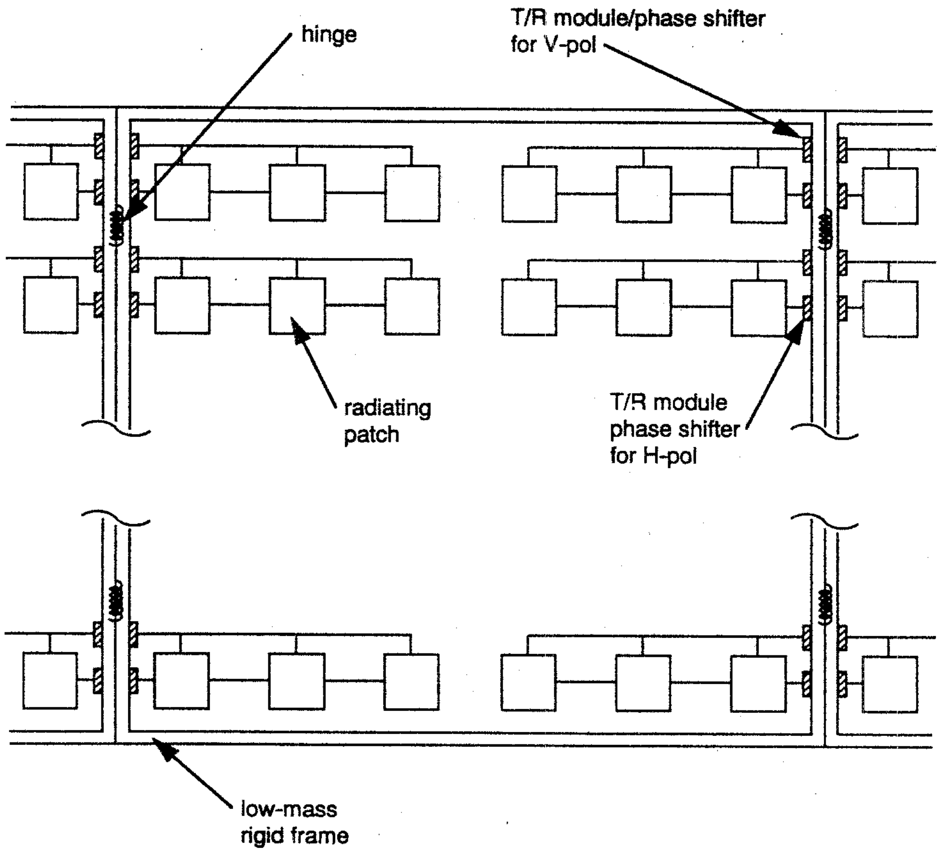

Fig. 7. Foldable frame-supported thin-membrane array.